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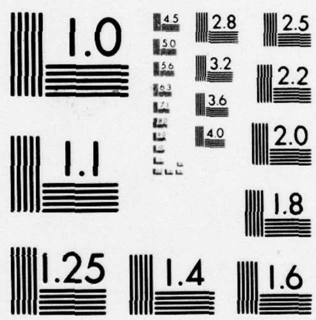
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U.S. Department of Transportation
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Office of Environment and Energy

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16. Abstract

Three approaches for reducing energy consumption were investigated: hardware modification, pilot education, and air traffic control. It is recommended that research into new aircraft engine designs, automatic mixture controls, conventional engine fuel saving improvements, composite materials development, and aerodynamic drag reduction continue and that this hardware be introducted into the fleet when cost, reliability and safty considerations allow.

It is further recommed (ed) that the pilot awareness and education programs listed above be implemented by the FAA and the general aviation industry; (and) finally, [that] the ATC actions listed should be futher evaluated to determine whether the anticipated fuel savings justify their implementation.

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EXECUTIVE SUMMARY

This report was prepared in response to the requirement of Section 681 of the National Energy Conservation Policy Act of 1978 (Public Law 95-619, November 9, 1978) to evaluate the energy conservation potential of recreational aircraft. In this study the term "recreational aircraft" is expanded to include all personal use of any aircraft since only a very small number of aircraft are designed and used solely for pure recreation.

This study is limited to General Aviation, and specifically to those basic types of aircraft normally used for personal operations, i.e., small single and twin engine, piston-powered, fixed-wing, less than 9,000 pounds normal gross weight, 1-10 passenger aircraft. Large multi-engine piston, turboprop, and turbojet fixed-wing aircraft, and roto-craft (helicopters, etc.) are primarily used for nonpersonal (commercial and business) purposes and are not addressed in this study since owner-ship and operating costs generally prohibit these aircraft from being owned by individuals or being used for large amounts of personal flying.

Three approaches for reducing energy consumption were investigated: hardware modification, pilot education, and air traffic control. Improvements are generally applicable to all small general aviation aircraft independent of operational category, and not limited to personal operations which account for only about one-fourth of all general aviation flying.

The 1977 General Aviation Activity and Avionics Survey was used as the primary source of aircraft usage and fuel consumption data for this study. FAA Aviation Forecasts Fiscal Years 1979-1990 were utilized to estimate future fuel consumption and aircraft usage. National production and demand figures for aviation gasoline were from information published for 1977 by the Energy Information Administration of the U.S. Department of Energy.

Specific Results

Aircraft Usage and Fuel Consumption

In 1977 there were 170,600 active single and twin engine piston aircraft which comprised 93% of the total U.S. general aviation fleet. A 45% growth to 247,400 aircraft is forecast for 1985 and 71% to 291,300 for 1990. The corresponding flight hours are forecast to grow 49% from 30.9 to 45.9 million hours by 1985 and 75% to 54.2 million hours by 1990.

The 1977 yearly aviation gasoline consumption of 451 million gallons for single and twin engine aircraft is forecast to grow 51% to 679 million gallons by 1985, and 79% to 808 million gallons by 1990. How ver, general aviation aircraft use very little (less than 1/2%) of the nation's gasoline supply. Of this amount approximately one-fourth, or less than 1/8% of the total motor gasoline consumed in the United States is used for personal flying including recreation.

Fuel Savings Programs

In the area of future development in engine improvements, a turbocharged engine operating at reduced engine speed and increased manifold pressure may offer a 10% fuel savings. Lean combustion concepts with advanced fuel injection and timing may yield a 7-10% savings per engine. Combining these two concepts may provide 10-20% savings overall if advances in engine cooling and means for minimizing detonation can be implemented. Advanced diesels have reported levels of specific fuel consumption amounting to 10-15% fuel savings over conventional aircraft engines although cost and weight penalties may preclude diesels from aircraft applications. Automatic mixture controls could save fuel and maintenance costs if questions involving unit cost, reliability, and certification can be satisfactorily resolved.

In the category of future development in airframe modifications, experts predict a possible savings of at least 25% in aircraft empty weight by using composites, which would lead to significant fuel savings. 10-30% increase in speed and miles per gallon is also possible by drag reduction on current airframe designs.

Pilot awareness and education programs offer the largest potential savings because, unlike the previous hardware modifications which address only future development for new aircraft, the opportunity exists for reaching all pilots and implementing fuel savings techniques in the total fleet. The following promising programs are identified as providing a possible annual savings of approximately 1.163 million barrels of aviation gasoline, or 10% of the total general aviation yearly consumption:

- --Fuel management instruction as part of the curriculum at flight instructor clinics.
- --Inclusion of energy conservation material into the FAA Accident Prevention Program.
- --Addition of questions on fuel conservation to license and rating examinations and modification of FAR Part 61 to require demonstration of proper leaning techniques and fuel efficient flight planning as part of flight tests.
- --Inclusion of fuel savings information in the Pilot's Operating Handbook, and
- --Increased emphasis on fuel conservation at flying schools and clubs.

Air traffic control procedures identified as having some limited potential for fuel savings are:

- --Flow control to lessen holding over the destination airport.

--Standard Instrument Departures and Standard Terminal Arrival Routes (SID's and STAR's) developed specifically for general aviation aircraft to save fuel.

--Separate general aviation runways to lessen separation and increase landing rate, and

--Area Navigation (RNAV) routes to permit point-to-point navigation.

Recommendations

It is recommended that research into new aircraft engine designs, automatic mixture controls, conventional engine fuel saving improvements, composite materials development, and aerodynamic drag reduction continue and that this hardware be introduced into the fleet when cost, reliability and safety considerations allow.

It is further recommended that the pilot awareness and education programs listed above be implemented by the FAA and the general aviation industry.

Finally, the ATC actions listed should be further evaluated to determine whether the anticipated fuel savings justify their implementation.

CHAPTER 1

1. INTRODUCTION

This study evaluates the energy conservation potential of recreational aircraft and was developed under the direction of the Office of Environment and Energy, Federal Aviation Administration pursuant to Section 681 of the National Energy Conservation Policy Act of 1978 (Public Law 95-619, November 9, 1978), which states, in part:

"Off-Highway Motor Vehicle Conservation Study

> Section 385. Not later than one year after the date of the enactment of this Section, the Secretary of Transportation shall complete a study of the energy conservation potential of recreational motor vehicles, including, but not limited to, aircraft and motor boats which are designed for recreational use, and shall submit a report to the President and to the Congress containing the results of such a study."

The FAA interprets the meaning of "but not limited to" in Section 385 to be applicable to the use of motor vehicles in recreational activity and not restricted to vehicles designed exclusively for recreational use. Due to considerations of cost of ownership and operation it quickly became apparent that any study of recreational aviation should focus on the "general aviation" portion of the industry. It was further determined that within that segment, the non-jet aircraft would be the most appropriate area of concentration.

Accordingly, this study focuses on: a determination of the current national consumption of aviation gasoline by general aviation; forecasts of future consumption assuming no new conservation programs, estimates of possible fuel savings resulting from aircraft hardware modifications and pilot oriented programs, and potential energy conserving air traffic control actions. Additionally, feasibility issues related to the various fuel saving options are discussed, and recommendations made for programs providing national aviation gasoline conservation potential.

To keep the potential benefits of such a conservation program in proper perspective, it should be remembered that all transportation needs accounted for approximately 20.6 quadrillion BTU's* of energy in 1978. Most of this demand was met by petroleum based fuel. General aviation used only 0.07 quadrillion BTU's of the total energy used in transportation to power multi and single engine piston aircraft. The

* Note: 1.00 quadrillion BTU's is approximately equivalent to 172 million barrels of oil.

recreational portion of the general aviation share is significantly less than this amount. Nevertheless, it is appropriate to develop a program to improve energy efficiency in all segments of society regardless of the amount of resultant savings.

CHAPTER 2

2. ESTIMATES OF CURRENT AND FUTURE FUEL CONSUMPTION

In this chapter, data from various sources are used to estimate the current annual aviation gasoline consumption, and FAA forecasts are used to estimate the future usage assuming current growth trends.

2.1 Approach to Fuel Usage Study

The National Energy Conservation Policy Act of 1978 requires an assessment of the energy conservation potential of off-highway motor vehicles including aircraft designed for recreational use.* In this aircraft study, "recreational use" is equated with all personal use, since only a very small number of general aviation aircraft** are designed and used solely for pure recreation (acrobatics, sightseeing, etc.). The FAA defines "personal operations" as individual flying for personal reasons and therefore travel, transportation, and flying to maintain pilot proficiency are additional uses that were investigated to identify energy conservation potential.

This study is limited to those basic types of aircraft normally used for "personal operations," i.e., small single engine and twin engine piston, fixed-wing, less than 9,000 lb. normal gross weight, 1-10 passenger aircraft. Large multi-engine piston, turboprop, and turbojet fixed-wing aircraft, and rotorcraft (helicopters, etc.) are primarily used for non-personal (commercial and business) purposes and are not addressed in this study since ownership and operating costs generally prohibit these aircraft from being owned by individuals or being used for large amounts of personal flying.

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* Aircraft do not lend themselves to the same categorization as do off-highway recreational motor vehicles such as all terrain vehicles and motor boats because of the large percentage of aircraft usage related to business and transportation. The General Aviation Manufacturers' Association (GAMA) estimates that 76% of all general aviation flying is done for business or commercial purposes.

** It should be noted that "general aviation" is defined as all aircraft in the U.S. Civil Air Fleet <u>except</u> those operated under Federal Aviation Regulations Parts 121 and 127 which cover the operations of fixed-wing aircraft and rotorcraft, and (1) have been issued a certificate of public convenience and necessity by the Civil Aeronautics Board authorizing the performance of scheduled air transportation over specified routes and a limited amount of non-scheduled operations, and (2) are used by large aircraft commercial operators. General aviation aircraft range in complexity from simple gliders and balloons to four engine turbojets.

Three approaches for reducing energy consumption were investigated: hardware modification, pilot education and air traffic control. Since these approaches are applicable to small general aviation aircraft independent of operational category, and since personal use accounts for only about one-fourth of all general aviation flying, it was decided to investigate fuel saving options for all operational categories including business and commercial.

2.2 Data Sources

The approach developed for this study required the identification of usage and fuel consumption data for small single engine and twin engine piston powered, fixed-wing aircraft by operational use. Nine general aviation operational categories are utilized by the FAA:

- Executive - Corporate flying with professional crew
- Business - All non-executive flying for business reasons
- Personal - Individual flying for personal reasons
- Aerial Application - Agriculture, health, forestry
- Instructional - Flying with or under supervision of a flight instructor
- Air Taxi - All Federal Aviation Regulations Part 135 passenger, cargo, and mail operations including charter
- Industrial Special - Patrol survey, photo, hoist, etc. - other than Part 135
- Aircraft Rental Business - Commercial flying club, leased, and rental aircraft activity.
- Other - R&D, government, air show, sales, parachuting, etc.

The FAA has collected comprehensive aircraft usage data in this format for some time. Prior to 1978, the FAA used the Aircraft Registration Eligibility, Identification and Activity Report, AC Form 8050-73 in its data collection program on general aviation activity and avionics. The form, sent annually to all owners of civil aircraft in the U.S., served two purposes: (1) Part 1 was the mandatory aircraft registration renewal form; (2) Part 2 was voluntary and applied to general aviation aircraft only, asking questions on the owner-discretionary characteristics of the aircraft such as flight hours, avionics equipment, base location, and use. In 1978, the FAA replaced AC Form 8050-73 with a new system to collect data for the previous year. Part 1 was replaced by a triennial registration program; Part 2 was replaced by the General Aviation Activity and Avionics Survey, FAA Form 1800-54 (see Appendix A). This survey is now scheduled to be conducted annually based on a statistically selected sample of general aviation aircraft requesting the same type of information as Part 2 of AC Form 8050-73 and owners' estimates of hourly fuel consumption.[1*]

* Reference 1, Page 1-3. References are identified numerically and listed at the end of the report.

Because of the availability of information, 1977 was chosen as the base year for this study. The 1977 survey[1] was used as the primary source of aircraft usage and fuel consumption data for this study. FAA forecasts[2] were utilized to estimate future fuel consumption and aircraft usage. National production and demand figures for aviation gasoline were taken from information published for 1977 by the Energy Information Administration of the U.S. Department of Energy.[3]

2.3 Aircraft Usage

The percent distribution by aircraft type of the 1977 active general aviation fleet is shown in Figure 2-1. There were 184,294 active (active is defined as those aircraft that were flown during the year) general aviation aircraft in 1977 which represented almost 87% of the total registered general aviation fleet. Nearly 93% are the aircraft types addressed in this study,* and from Figure 2-2 it can be seen that these aircraft flew 86% of the total general aviation hours logged in 1977. Figures 2-3 through 2-6 show the distribution of flight hours by primary use. The FAA defines primary use as the operational category for which the largest number of flight hours are reported and all flight hours are then listed under that primary usage category. For example, an aircraft that is flown 50 Personal hours, 40 Business hours, and 30 Instructional hours in a given year is classified as a Personal aircraft because of its primary use, and the total 120 hours flight time is reported as Personal. Therefore, in Figure 2-6, the 26.9% Personal distribution of total hours flown comprises the total flight time of all those single and twin engine piston aircraft whose primary use is Personal. This distribution data then cannot strictly be used to determine the actual hours flown in any usage category; but, assuming that the non-primary use hours tend to balance out between categories, it is estimated that roughly one-fourth of the hours flown by small aircraft are for personal reasons: sport flying, transportation, proficiency, etc., whereas three-fourths are for business and commercial uses. This agrees with the General Aviation Manufacturers Association estimate mentioned previously of 76%.

--Forecast

The active general aviation fleet forecasts for single and twin engine piston active aircraft for 1985 and 1990 are shown in Tables 2-1 and 2-2.

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* i.e., single or twin engine piston, fixed-wing, less than 9,000 lb. normal gross weight, 1-10 passenger aircraft. There remains a few large aircraft (over 9,000 lb.) in the twin engine piston category which are not included in this study.

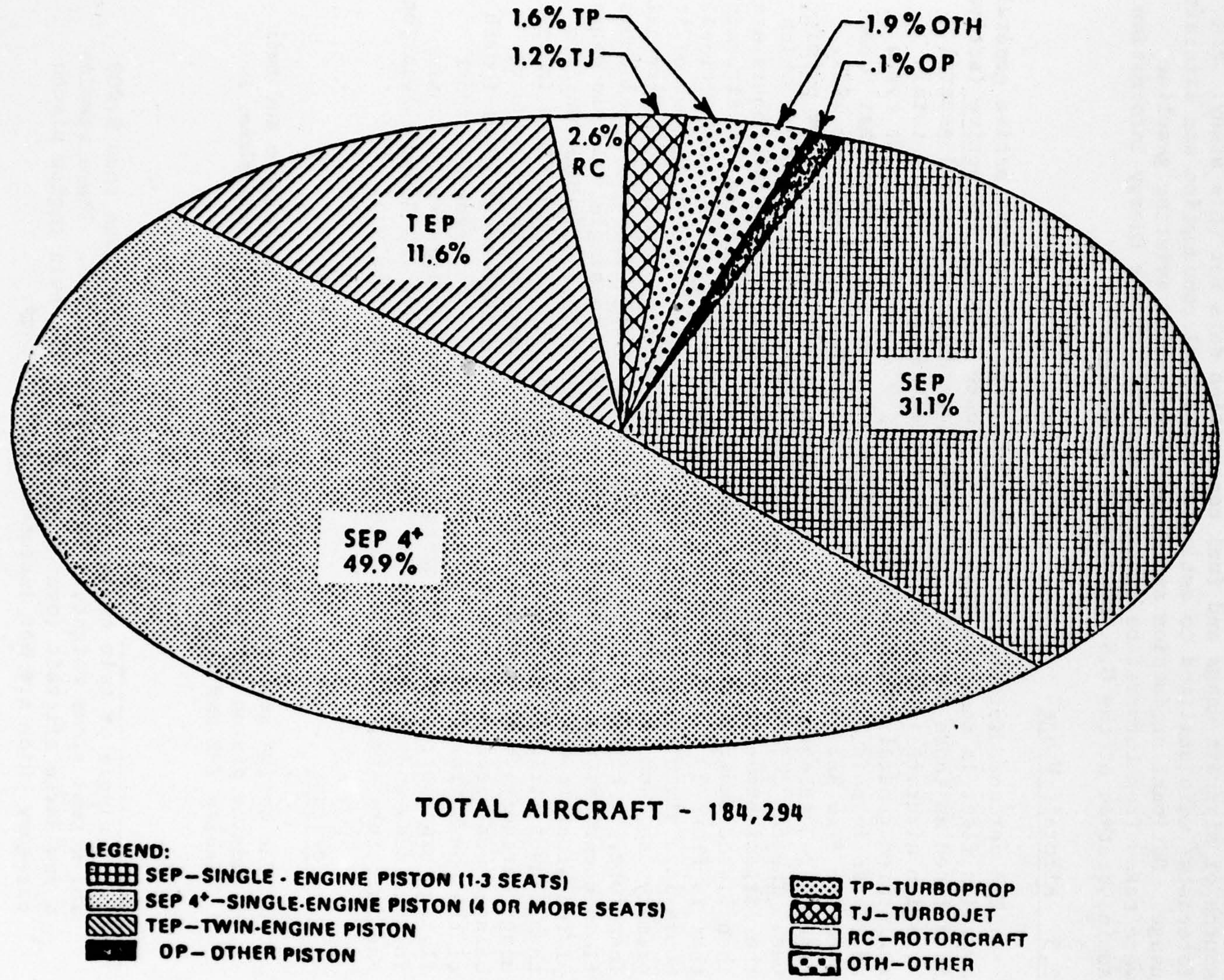


Figure 2-1. Percent Distribution of Active General Aviation Fleet by Aircraft Type - 1977

Source: 1977 General Aviation Activity and Avionics Survey, Reference 1, Table 2-4

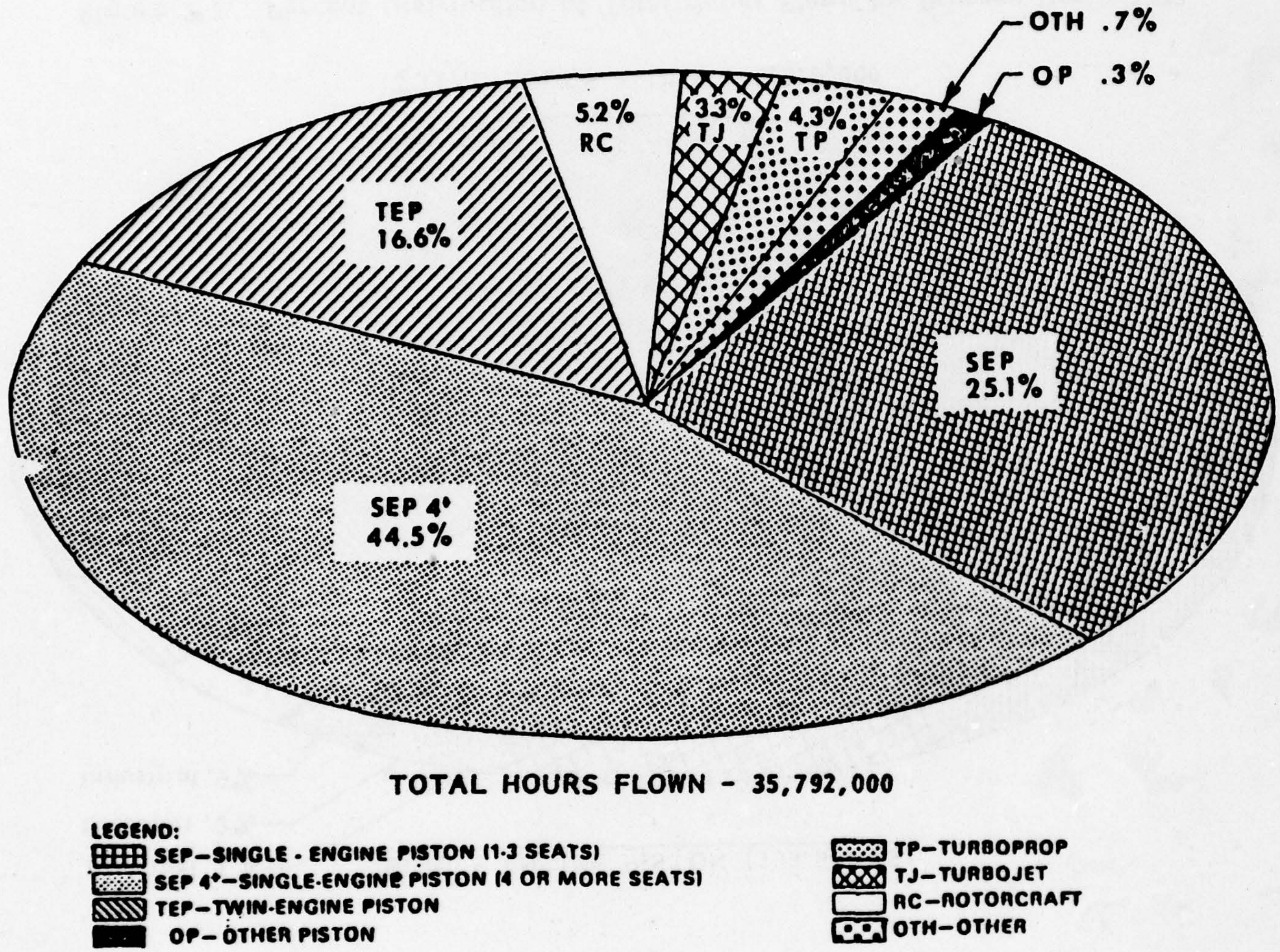


Figure 2-2. Percent Distribution of Total Hours Flown by Aircraft Type - 1977

Source: 1977 General Aviation Activity and Avionics Survey, Reference 1, Table 1-7

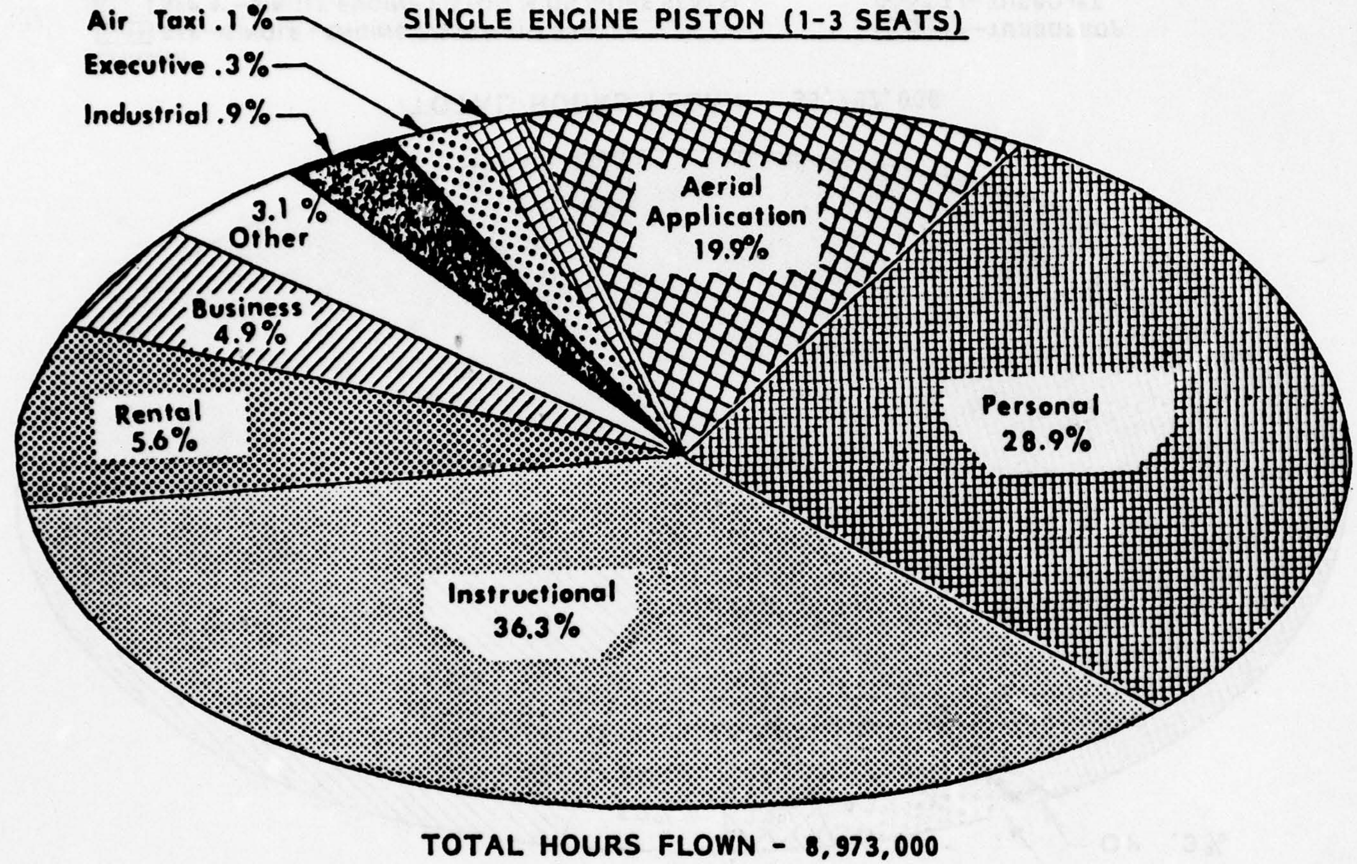
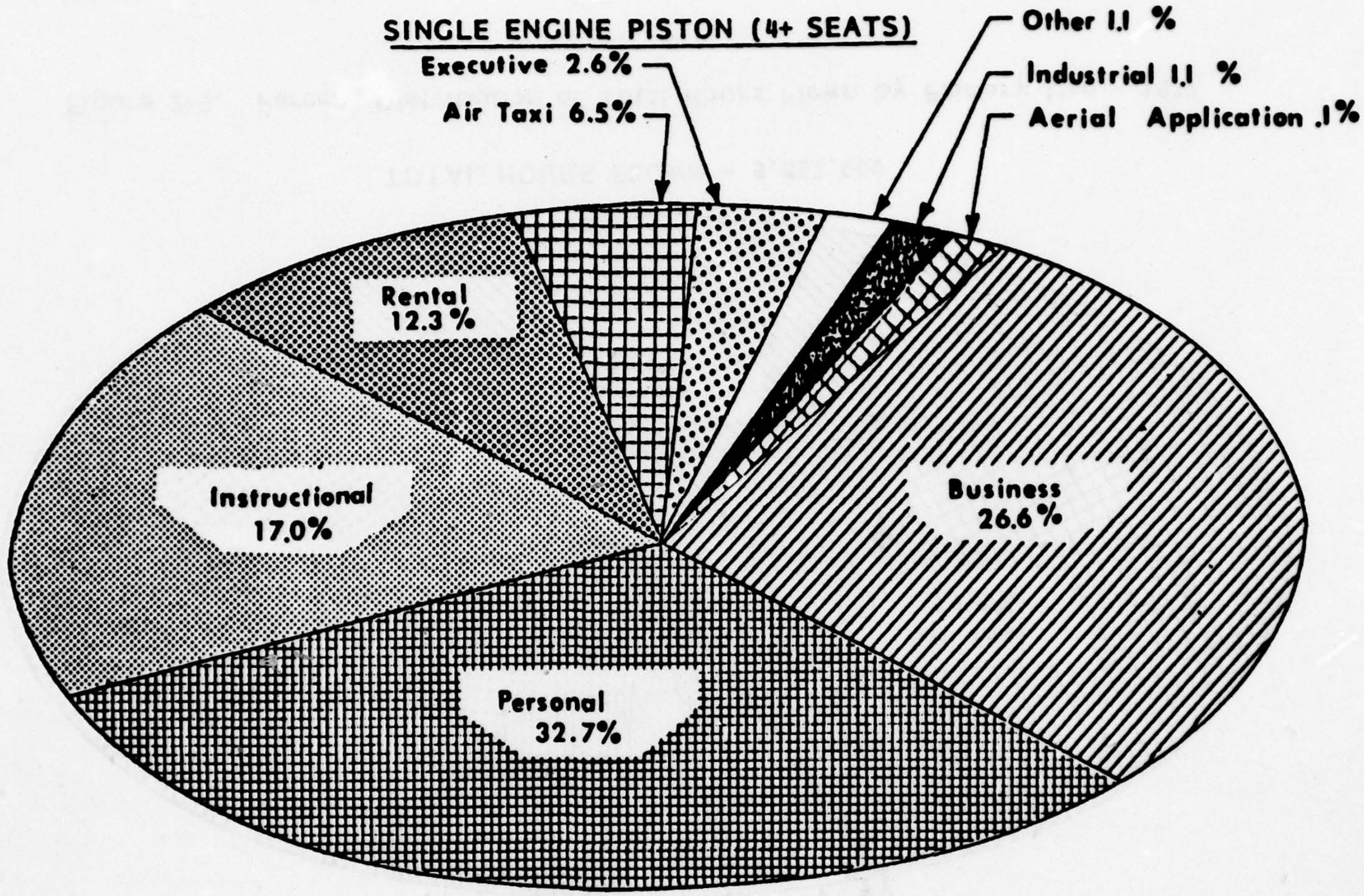


Figure 2-3. Percent Distribution of Total Hours Flown by Primary Use - 1977

Source: 1977 General Aviation Activity and Avionics Survey, Reference 1, Table 2-4



TOTAL HOURS FLOWN - 15,944,000

Figure 2-4. Percent Distribution of Total Hours Flown by Primary Use - 1977

Source: 1977 General Aviation Activity and Avionics Survey, Reference 1, Table 2-4

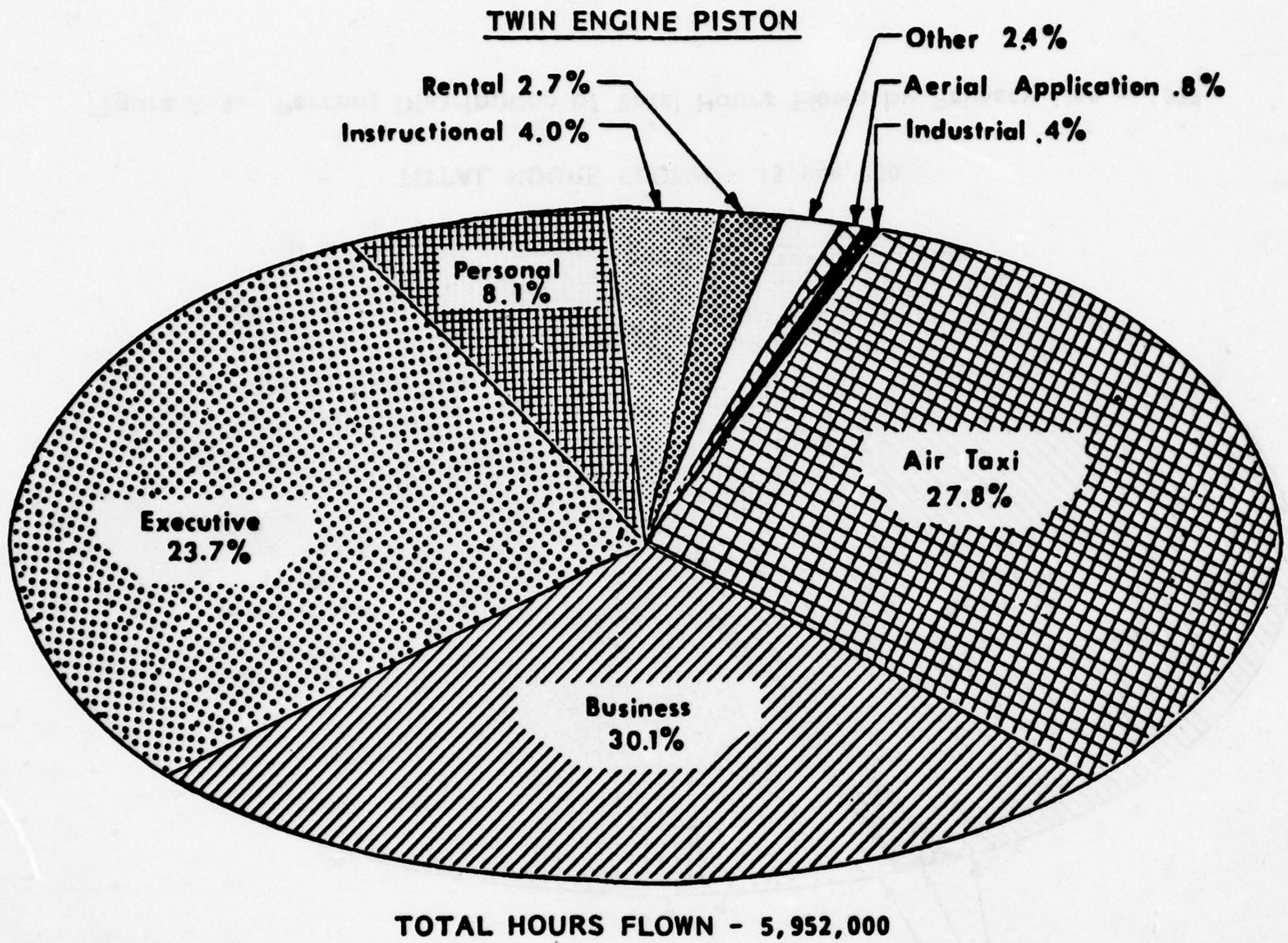
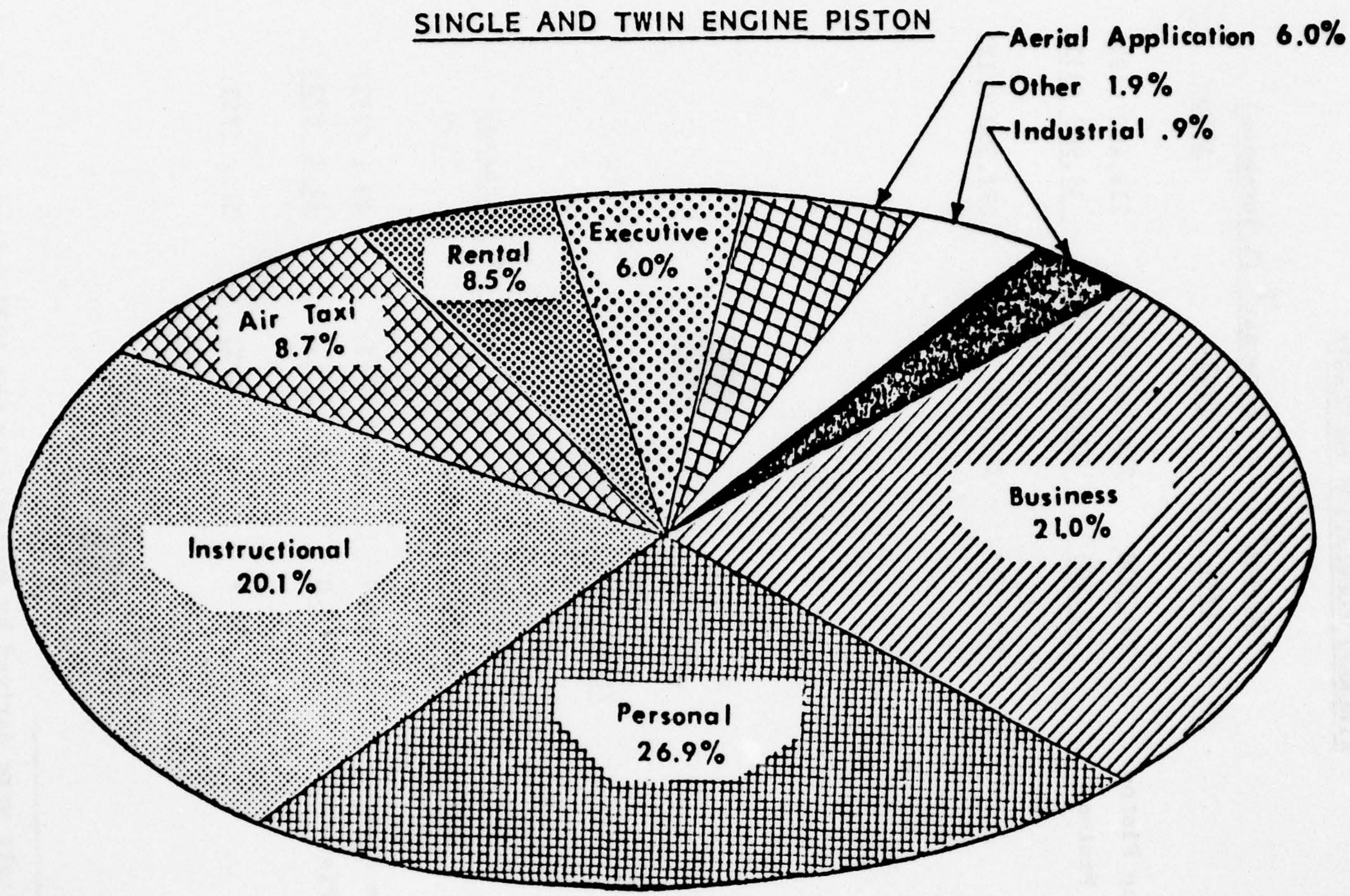


Figure 2-5. Percent Distribution of Total Hours Flown by Primary Use - 1977

Source: 1977 General Aviation Activity and Avionics Survey, Reference 1, Table 2-4



TOTAL HOURS FLOWN - 30,868,000

Figure 2-6. Percent Distribution of Total Hours Flown by Primary Use - 1977

Source: 1977 General Aviation Activity and Avionics Survey, Reference 1, Table 2-4

TABLE 2-1

AIRCRAFT POPULATION FORECAST*

	Survey[1]	Forecast[2] (% increase)	
	1977	1985	1990
Single Engine Piston	149,300	214,900 (44%)	252,400 (69%)
Twin Engine Piston	21,300	32,500 (53%)	38,900 (83%)
Total	170,600	247,400 (45%)	291,300 (71%)

TABLE 2-2

FLIGHT HOUR FORECAST*
(in millions)

	Survey[1]	Forecast[2] (% increase)	
	1977	1985	1990
Single Engine Piston	24.9	36.7 (47%)	43.1 (73%)
Twin Engine Piston	6.0	9.2 (55%)	11.1 (87%)
Total	30.9	45.9 (49%)	54.2 (75%)

* These forecasts were derived by multiplying the 1977 values reported in Reference 1, Tables 2-4 and 2-9, by the percent growth rates taken from Reference 2, Tables 9 and 11.

2.4 Fuel Consumption Estimates

2.4.1 Aircraft Hourly Fuel Consumption

The 1977 General Aviation Activity and Avionics Survey asked aircraft owners to report estimated aircraft hourly fuel consumption (see Appendix A, item no. 8). This raw survey data was used to calculate average hourly fuel consumption estimates which are presented in Table 2-3 for four aircraft classes (single engine piston aircraft of 1-3 seats and over 3 seats; and twin engine piston aircraft of 1-6 seats and over 6 seats).

--Forecast

Using the flight hour percent growth forecasts from Table 2-2, 1977 fuel consumption from Table 2-3, and assuming that aircraft average hourly fuel consumption will remain unchanged, fuel usage is forecast for 1985 and 1990 in Table 2-4.

Therefore, fuel consumption is projected to increase 79% for single and twin engine piston aircraft between 1977 and 1990 if no conservation activity is initiated.

2.4.2 National Aviation Fuel Consumption

Figure 2-7 shows the percent consumption by major user of aviation gasoline (avgas) in 1977. Domestic demand[3] for avgas that year was 13,932,000 barrels which was .53% of the total U.S. gasoline demand of 2,633,472,000 barrels. From Figure 2-7 it can be seen that general aviation consumed 78% of the aviation gasoline (10,867,000 barrels) or .41% of the total national gasoline demand. Since piston engine powered general aviation includes some helicopters and large multi-engine fixed-wing aircraft, the small aircraft addressed in this study therefore consumed substantially less than 1/2% of the Nation's gasoline in 1977. Of this amount approximately one-fourth, or less than 1/8% of the total motor gasoline in the U.S. was used for personal flying: recreation, travel, proficiency, etc.

2.4.3 Comparison of Fuel Consumption Estimates

From the estimates in Section 2.3 of hourly fuel consumption for single and twin engine aircraft, an estimated 10,729,000 barrels of aviation gasoline was consumed in 1977. For that same year the Department of Energy[3] reported total avgas consumption of 13,932,000 barrels, of which 10,867,000 barrels, or 78%, were used by general aviation. Therefore, the calculated usage based on hourly data was 98.7% of the total reported demand. This is reasonable agreement since piston helicopters and fixed-wing, multi-engine piston aircraft are not included in the hourly estimate and can account for the difference.

TABLE 2-3

AVIATION GASOLINE CONSUMPTION BY HOURLY ESTIMATES - 1977

	Average Hourly Fuel Consumption * (gal/hr)	Total Hours Flown**	Total Fuel Consumption* (gal in thousands)
Single engine 1-3 seats	8.2	8,972,836	73,260
Single engine 4+ seats	11.0	15,943,601	176,070
Twin engine 1-6 seats	26.8	3,630,265	97,330
Twin engine 7+ seats	44.8	2,321,563	103,970

1977 Total Fuel Consumption = 450,630,000 gallons

= 10,729,000 barrels

TABLE 2-4

FUEL CONSUMPTION FORECAST

(in thousands of gallons)

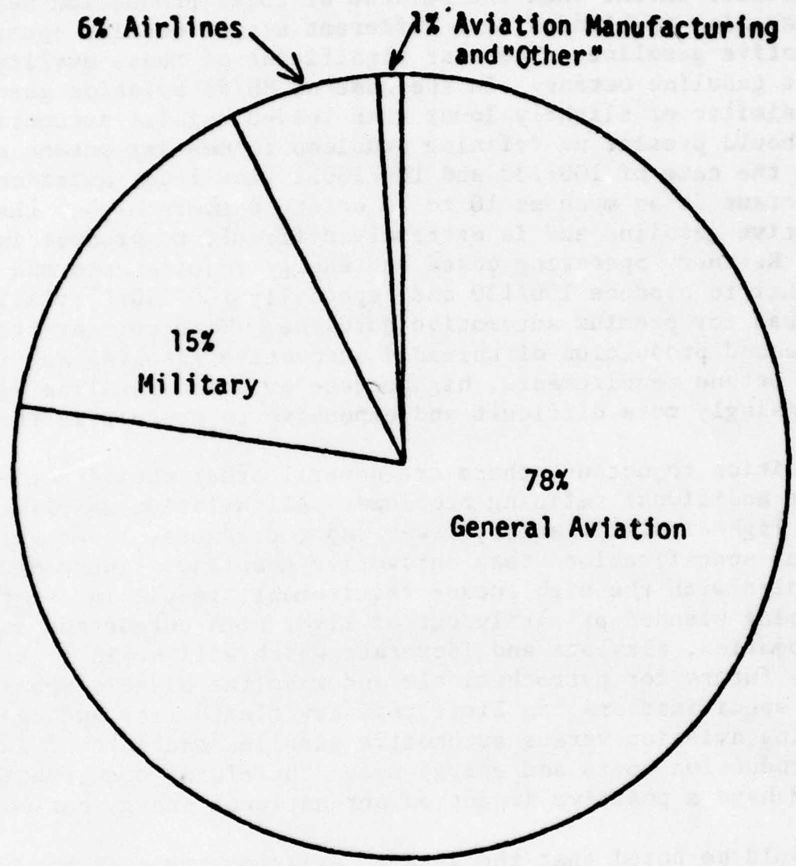
	Current	Forecast (% increase)	
	1977	1985	1990
Single Engine Piston	249,330	366,515 (47%)	431,341 (73%)
Twin Engine Piston	201,300	312,015 (55%)	376,431 (87%)
Total	450,630	678,530 (51%)	807,772 (79%)

* Data for average hourly fuel consumption and estimated total fuel use from the Office of Management Systems, Federal Aviation Administration, Washington, D.C. This data is for all user categories: Personal, Business, Rental, etc.

** Reference 1, Table 2-4.

FIGURE 2-7

USES OF AVIATION GASOLINE - 1977



Source: U.S. Congress, House of Representatives, Subcommittee on Energy and Power, Committee on Interstate and Foreign Commerce; "Statement of David J. Bardin, Administrator, Economic Regulatory Administration, Department of Energy, February 8, 1979".

2.4.4 Impact of Aviation Gasoline Production on Refinery Output

It has been shown that the small piston powered, general aviation aircraft uses very little (less than 1/2%) of the Nation's gasoline supply. However, manufacture of avgas may affect total motor gasoline output to a greater extent than the percent of total production may imply. Aviation gasoline is blended to a different set of quality specifications than automotive gasoline. The most significant of these quality differences is gasoline octane. In the case of 80/87 aviation gasoline, octane is similar or slightly lower than leaded regular automotive gasoline and should present no refining problems in meeting octane specifications. In the case of 100/130 and 100/130LL (low lead) aviation gasoline, however, octane is as much as 10 to 15 octane numbers higher than premium automotive gasoline and is extremely difficult to produce in the refinery. Refinery operating costs and energy requirements are significantly higher to produce 100/130 and especially 100/130LL aviation gasoline than for premium automotive gasoline. With current trends towards increased production of unleaded automotive gasoline and increasing automotive octane requirements, high octane aviation gasoline will become increasingly more difficult and expensive to produce in the future.

In addition to octane, there are several other specifications that can present additional refining problems. All aviation gasoline is blended to lighter distillation, lower vapor pressure, lower sulfur and freeze point specifications than automotive gasoline. These specifications, coupled with the high octane requirement, result in aviation gasoline being blended primarily out of light high octane components such as aromatics, alkylate and isomerate which will be in greater demand in the future for petrochemicals and gasoline blend components. All of the specifications can limit refinery flexibility and capacity for producing aviation versus automotive gasoline and further increase refinery production costs and energy use. Therefore, conservation of avgas could have a positive impact on our national energy outlook.

It should be noted that the general aviation industry has been told by the refiners that 80/87 and 100/130 octane avgas will eventually be phased out of production so that one grade only, 100/130LL, will have to be used in all aircraft. This requirement has led the manufacturers to introduce new engines for the lower powered aircraft requiring 100/130LL that previously used 80/87 grade. In view of the cost and availability concerns related above, it would seem that the decision to cease or limit production of 80/87 low octane aviation gasoline should be reassessed.

CHAPTER 3

3. ASSESSMENT OF POTENTIAL FUEL SAVINGS

3.1 Hardware Modifications

In this section, fuel conserving modifications to aircraft engines and airframe components are evaluated. Some estimates are made of the percent fuel savings available by implementing these improvements and relevant cost, safety, and performance factors are discussed.

3.1.1 Engine

As an introduction to this section on engine concepts for reducing energy consumption, a brief discussion of basic engine behavior under a variety of operating modes and for different design features is presented to set the stage for examining energy saving options. The fundamental parameters affecting basic engine efficiency are:

--compression ratio
--air-fuel mixture ratio
--manifold pressure
--engine friction

A. Basic Engine Behavior

The effect of compression ratio and fuel/air mixture ratio on engine performance is expressed in the idealized engine efficiency relation given below.

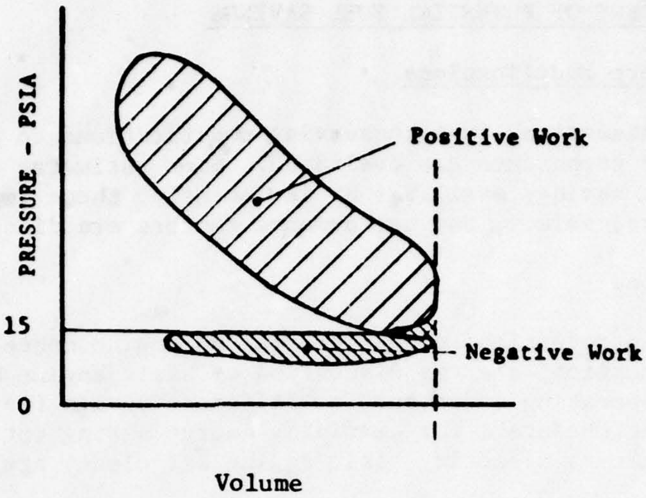
$$\text{Ideal Engine Efficiency} = 1-\left(\frac{1}{CR}\right)^{K-1}$$

CR = Compression Ratio

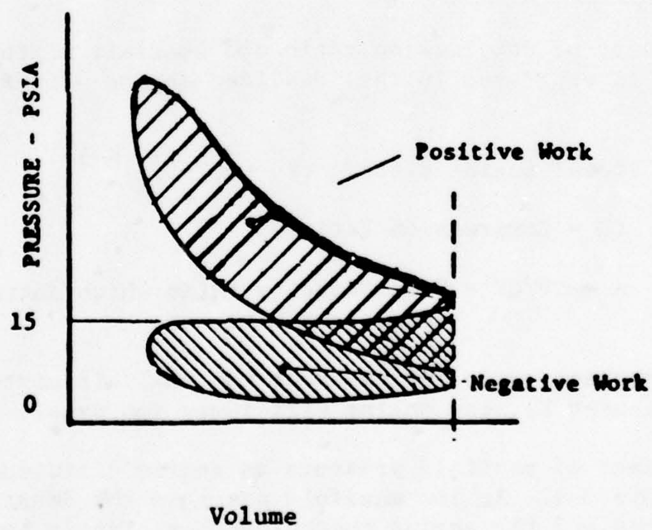
K = CP/CV = Heat Capacity Ratio which increases for leaner mixtures.

As the compression ratio increases or the fuel/air mixture ratio is leaned (increased K), the engine efficiency improves.

The effect of manifold pressure on engine efficiency is characterized in Figure 3-1. At low manifold pressure the density of the intake air is reduced and the engine must provide a greater amount of work to draw the mass of air required for combustion into the cylinder. This negative work is called pumping loss. As the manifold pressure increases and a greater mass flow rate of air is drawn into the cylinder the torque output of the engine increases (at constant engine speed). Negative pumping work is minimized by operating the engine at high manifold pressure (wide open throttle). This can be seen in the typical engine



Case a) High Manifold Pressure - High Efficiency



Case b) Low Manifold Pressure - Low Efficiency

FIGURE 3-1 - TYPICAL PRESSU' VOLUME DIAGRAMS FOR THROTTLED ENGINE ILLUSTRATING PUMPING LOOP.

Source: Reference 4

map shown in Figure 3-2 in which efficiency (BSFC)* lines show that maximum efficiency occurs at high torque (or brake mean effective pressure (BMEP)) and low engine speed (RPM).

Manifold pressure, torque and brake mean effective pressure can be used synonymously when the engine speed is held constant. The BMEP is the work output of the engine per cycle divided by the piston area and is directly proportional to the engine torque output. The mean effective pressure (torque) characterizes the level of combustion pressure in the cylinder. A typical naturally aspirated automotive engine is designed for a maximum BMEP of about 150 pounds per square inch. This represents the upper limit to which the engine is designed from a mechanical and a combustion standpoint. BMEP operation beyond this level requires increased engine strength and generally, higher fuel octane ratings. As the BMEP increases beyond 150 psi elements of fuel may auto ignite at the high cylinder temperatures in a non-controlled manner (detonation or knock). At this knock or detonation limit the output of the engine rapidly decreases as fuel is burning in an uncontrolled manner. Increased compression ratio, or manifold pressure increases the BMEP. For a naturally aspirated engine the maximum manifold pressure is the local ambient air pressure (which decreases with altitude for an aircraft engine). Higher manifold pressures can be achieved with turbocharging up to the BMEP limit. The effect of engine friction on efficiency is obvious; as engine friction increases the useful output is reduced. Engine friction is generally proportional to the engine speed. With constant horsepower and lower engine speed (torque or BMEP increased) the proportion of friction to useful combustion energy is reduced and the engine efficiency increases.

The highest manifold pressure, the highest BMEP, and the most lean combustion achievable in conventional reciprocating engine design is embodied in the diesel engine. The diesel engine is always operated at the highest manifold pressure available (atmospheric if naturally aspirated or higher if supercharged), at extremely lean mixtures (1/10 of the overall cylinder fuel to air ratio than the most lean spark ignited engine), and at lower speeds than spark ignition engines. The diesel engine generally offers efficiency gains over conventional spark ignited engines particularly when the engine is required to operate at less than 50 percent of rated power for extended amounts of time (i.e., idle).

B. Aircraft Engine Design

Table 3-1 shows a typical usage profile for a General Aviation airplane. Less than 13% of the trip fuel is consumed during taxi, takeoff and landing, and an insignificant fraction of typical usage is at less than 50% power. Cruise mode (55-75% of maximum rated power) is the

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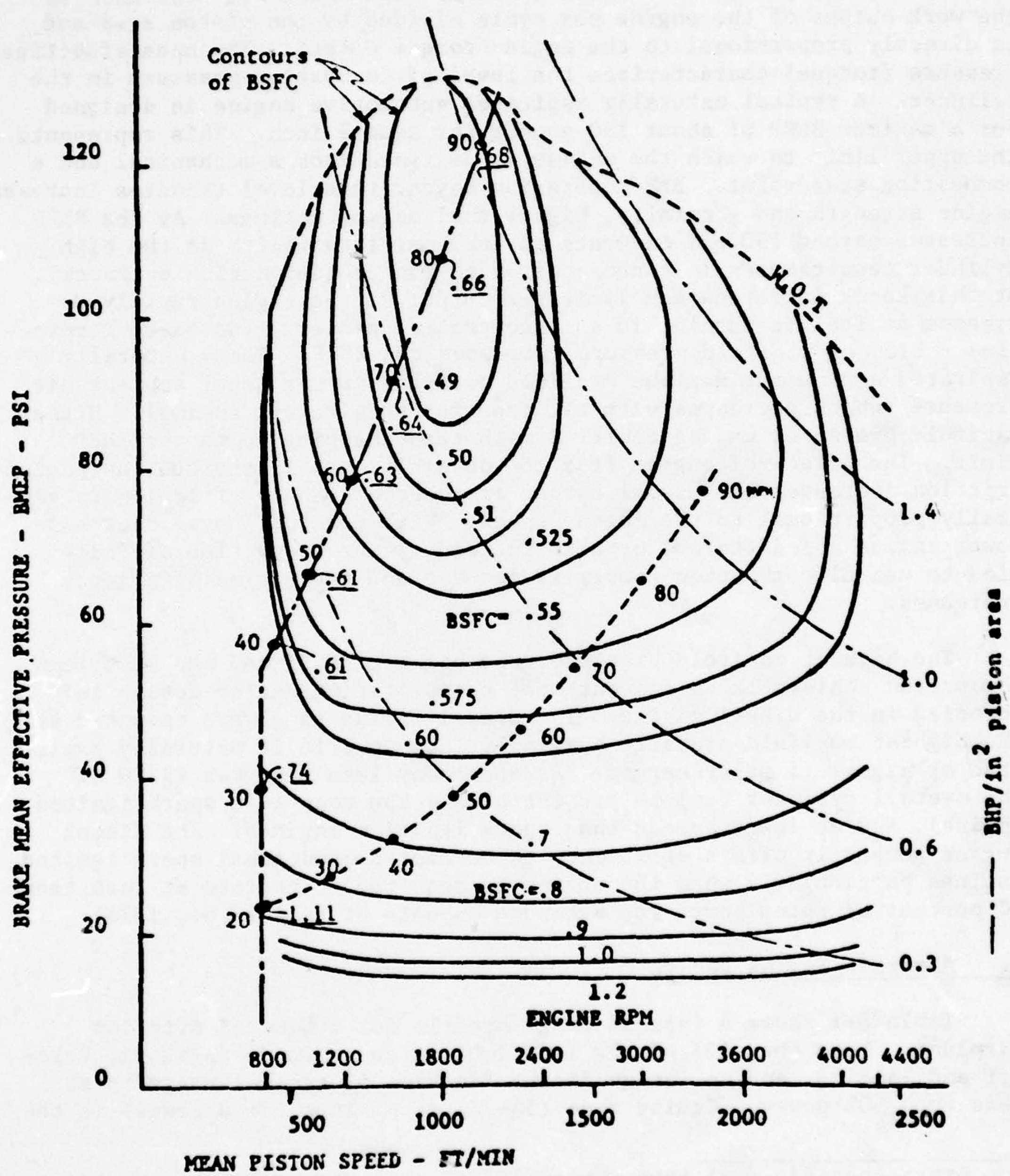
* Brake specific fuel consumption (BSFC is a measure of the pounds of fuel used per brake-horsepower of useful output and is a measure of engine efficiency.

FIGURE 3-2

PERFORMANCE MAP - TYPICAL AUTOMOTIVE GASOLINE ENGINE

300 IN^3 V-8



Source: Reference 4

TABLE 3-1

% OF FUEL CONSUMPTION BY AIRCRAFT OPERATIONAL MODE

	% of Max Power	% of Trip Fuel
Landing, Take Off	40%, 100%	13%
Cruise @ 6000'	65%	87%

Source: Reference 5

TABLE 3-2

BASELINE ENGINES

	Production Aircraft Engines		Automotive Engines	
	Naturally Aspirated (Ref 5)	Turbo Charged (Ref 6)	Naturally Aspirated (Ref 4)	Diesel
BHP (2200-2700 PRM)	285	210	200	150
Compression Ratio	8.5	7.5	7.5	20.5
Minimum BSFC @ Cruise	.43	.42	.49	.43

principal fuel consuming mode of operation. During cruise the minimum achievable BSFC of production aircraft engines is better than reported values for most automotive diesel engines and all spark engines. Substantial fuel economy gains at the typical 65% rated power, 6000' cruise condition cannot therefore be achieved by adaptation of present automotive spark or diesel engine design to aircraft applications and design changes specifically related to aircraft engine operation during typical aircraft missions will be necessary to improve the efficiency of current technology aircraft engines.

The typical aircraft engine operates at relatively high compression ratio compared to automotive engines and in a fairly narrow speed range (2,000-2,700 RPM), as shown in Table 3-2.

During the cruise mode at 6,000 ft. a typical naturally aspirated aircraft engine developing 65% of rated power is operating at wide open throttle.* No increase in manifold pressure is possible. No decrease in engine speed is possible while maintaining constant power (unless a larger engine is substituted). Leaning of the engine fuel/air ratio at cruise is generally achieved manually and is typically set somewhat rich of peak exhaust gas temperature (EGT) whereas best fuel economy is slightly lean of peak EGT. Leaning of the engine fuel/air ratio to reduce fuel consumption is limited by fundamental engine characteristics. The turbocharged aircraft engine has the same basic mixture limitations as naturally aspirated. As the mixture is leaned the probability of an ignitable mixture residing in the zone around the spark plugs is reduced. At the "lean limit" irregular ignition occurs as the spark is unable to reliably ignite the combustible mixture. In a standard aircraft engine the operator can lean to near this limit. Improved lean combustion concepts (stratified charge or hydrogen enrichment) designed to lower the lean limit focus on providing a richer combustible mixture near the spark plug while maintaining an overall lean cylinder mixture. The diesel engine can be run at extremely lean overall mixture ratios as the fuel self ignites and the difficulty of providing a reliable combustible mixture within a specific location in the cylinder is not a problem.

C. Potential Energy Savings

Increased Manifold Pressure

Using reduced engine speed and increased torque (manifold pressure, BMEP) to maintain a given power level is one means of increasing fuel efficiency. In a naturally aspirated engine the manifold pressure is limited by the ambient air conditions and therefore available power

* Decreasing ambient pressure (density) due to ascending altitude reduces available engine power from sea level rated conditions.

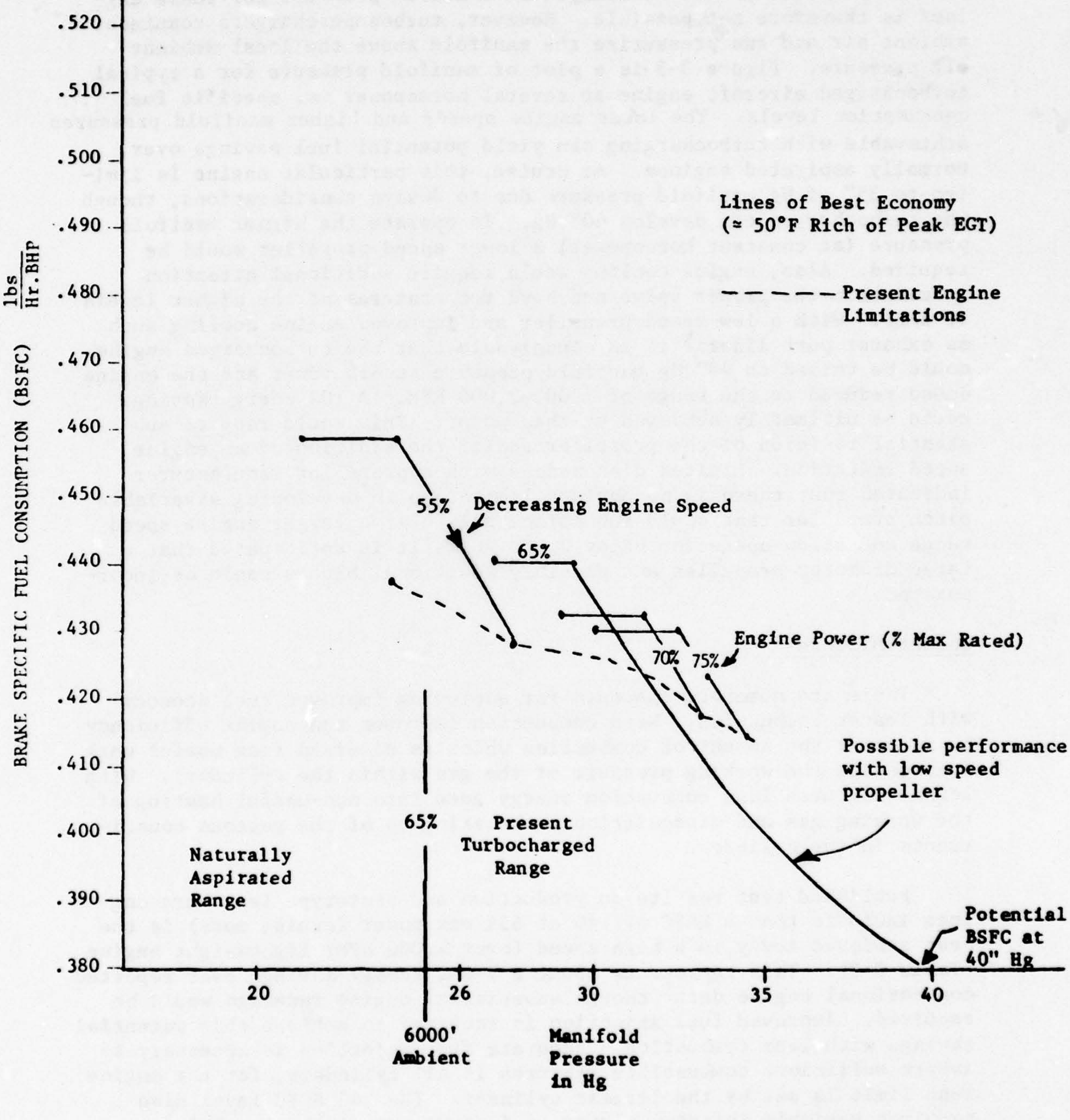
decreases with altitude. At normal cruise conditions, full throttle (maximum available manifold pressure) is usually required to attain desirable cruise power. Increases in manifold pressure for these engines is therefore not possible. However, turbosuperchargers compress ambient air and can pressurize the manifold above the local ambient air pressure. Figure 3-3 is a plot of manifold pressure for a typical turbocharged aircraft engine at several horsepower vs. specific fuel consumption levels. The lower engine speeds and higher manifold pressures achievable with turbocharging can yield potential fuel savings over normally aspirated engines. At cruise, this particular engine is limited to 35" of Hg manifold pressure due to design considerations, though the turbocharger can develop 40" Hg. To operate the higher manifold pressure (at constant horsepower) a lower speed propeller would be required. Also, engine cooling would require additional attention to maintain the proper valve and head temperatures at the higher levels of BMEP. With a low speed propeller and improved engine cooling such as exhaust port liners[5] it is conceivable that the turbocharged engine could be raised to 40" Hg manifold pressure at 65% power and the engine speed reduced to the range of 1,000-2,000 RPM. A 10% energy savings could be ultimately achieved at this point. This would require substantial revision of the propeller and/or the addition of an engine speed reduction. Limited discussions with a propeller manufacturer indicated that there is no obvious limitation in developing a variable pitch propeller that could run efficiently over a larger engine speed range and allow operation below 2,000 RPM. It is anticipated that a large diameter propeller and possibly additional blades could be incorporated.

Leaner Mixtures

There are numerous concepts for achieving improved fuel economy with leaner combustion. Lean combustion improves the engine efficiency by reducing the amount of combustion which is diverted from useful work (increasing the working pressure of the gas within the cylinder). With leaner mixtures less combustion energy goes into non-useful heating of the working gas and dissociation or breaking up of the gaseous constituents in the cylinder.

Published test results on production and prototype lean burn engines indicate that a BSFC of .40 at 65% max power (cruise mode) is the best achieved today in a high speed (over 1,000 RPM) lightweight engine (Table 3-3). This represents about a 7-10% energy savings over reported conventional engine data[5] though substantial engine redesign would be required. Improved fuel injection is required to achieve this potential savings with lean combustion. Accurate fuel injection is necessary to assure sufficient combustible mixtures in all cylinders, for the engine lean limit is set by the leanest cylinder. The .40 BSFC level also requires variable ignition timing, a feature not presently used on standard aircraft engines.

FIGURE 3-3



FUEL CONSUMPTION VS MANIFOLD PRESSURE

Source: Reference 6

TABLE 3-3

ALTERNATIVE ENGINE CONCEPTS

	RPM	%. POWER	BEST BSFC	% SAVING IN CRUISE(65% POWER)
Standard Aircraft Engine (Ref 5)	2300	65	.43	Baseline
LEAN BURN				
Lean Burn (Hydrogen Enrichment) (Ref 7)		65	.43	0
Avco Rotary (Ref 7)	2400	75	.41	5%
Stratified Charge (Ref 4)	2000	65	.40	7%
DIESEL ENGINES				
High Speed (Lightweight) Diesel (Ref 4)	2000	65	.43	0
Hyperbar Diesel Co. (Ref 7)			.38	12%

Diesel Engines

Most current automotive diesels do not offer fuel economy savings over the baseline aircraft engine. These diesels excel in low percent power applications. Work[7] on special highly turbocharged (high BMEP) diesel engines has developed a reported .38 BSFC in the cruise mode. This is a notable achievement as it comes close to the .36 BSFC of the large bore stationary highly turbocharged engine operating at the highest BMEP levels (300 psi) reported in the literature. The high BMEP aircraft concept apparently involves a secondary combustion chamber in the exhaust gas ahead of the turbine of the turbocharger to provide additional turbocharging capability.

Summary of Engine Modifications

Turbocharged engines operating at reduced engine speed and increased manifold pressure and torque may offer a 10% fuel savings. Improved engine cooling may be required in order to operate these turbocharged engines at high manifold pressures and a lower speed propeller (or drivetrain speed reduction) would be needed to provide required power at cruise.

Lean combustion with advanced fuel injection and timing may yield a 7-10% fuel savings. If advances in engine cooling and means for minimizing detonation (such as water injection) can be implemented, the lean burn engine could be combined with the high manifold pressure-low speed concept, possibly achieving a 10-20% savings overall.

Advanced high BMEP diesels (Hybar) have reported levels of BSFC amounting to a 10-15% fuel savings over conventional aircraft engines. The cost and weight penalty of incorporating a highly turbocharged diesel into light commercial aircraft should be realistically examined.

3.1.2 Automatic Mixture Controls

The foregoing analysis has used as its baseline an engine that was properly leaned at cruise. As will be seen in Section 3-2, an increase in cruise fuel consumption of 15-20% results when the mixture control is improperly set at the full rich position while at cruise power. In some applications, automatic mixture controls may be beneficial to achieve proper engine operation and minimum fuel consumption. The automatic mixture control schedules proper engine fuel/air ratio for the flight condition and therefore relieves the pilot of the need to manually lean the engine mixture with each power and altitude change. Automatic mixture controls are not new but are used only in a few expensive, sophisticated aircraft. A new control is currently being developed which incorporates the throttle, mixture, and propeller speed controls into a single lever. This unit schedules the engine/propeller combination to provide efficient operation over a range of flight conditions. Since these controls are all hydromechanical and follow preset mixture schedules, they cannot adjust mixture based on actual engine operational data (such

as manifold pressure and exhaust gas temperature) and do not provide the precision that a modern electronic fuel control could. A reliable electronic control, inexpensive enough to be installed in smaller aircraft, could save significant amounts of fuel as well as protecting engines from possible damage due to incorrect leaning.

3.1.3 Airframe Modifications

Fuel saving hardware modification to airframe components primarily involve drag and weight reduction, since in both cases, engine power can be lowered, resulting in lower fuel consumption. Drag has a definite relationship with thrust, and weight with lift. Lift is required to counteract the aircraft weight and therefore reduced weight allows reduced lift. Reduced lift, in turn, allows a smaller (i.e., lighter) wing, more weight reduction, and reduced drag. Thrust is required to overcome drag. The relative motion of the air over an aircraft that produces lift also generates drag, which is the backward deterrent force caused by the resistance of the air to the aircraft moving through it. The total drag is primarily composed of induced drag (caused by turbulence associated with wingtip vortices produced by the generation of lift); parasite drag (losses associated with the air resistance of the airframe including skin losses), and profile drag (parasite-type drag of the airfoils). Drag reduction results in less required thrust which allows reduced engine weight-size and required fuel capacity; or alternatively, higher cruise speeds.

Aircraft designers are looking towards composite materials to reduce aircraft gross weight and empty weight in basic airframe structure, landing gear, and propeller blades. Experts predict a possible savings of at least 25% in empty weight by using composites. However, before these materials can be introduced into general aviation, many developments are necessary, including lightning protection, inspection and testing techniques, interfacing with metals, new approaches to structural analysis and design, new manufacturing techniques, and methods for field repairs. Also, cost must drop sharply from current levels for composites to be practical in small aircraft.

Drag reduction programs can be aimed at reducing all types of drag. One manufacturer believes that 30% increase in speed (and miles per gallon) is available in current aircraft designs by drag reduction. Others estimate the possible savings to be nearer to 10% due to different design philosophies and a more conservative outlook. Some of the improvements possible are semi-cosmetic (reduced parasite and profile drag caused by airframe bumps, rivets, scoops, etc.), and others non-cosmetic (new wing design, engine cowling design, flaps, incorporation of retractable landing gear into more aircraft designs, etc.). It is anticipated that tradeoffs involving first cost, payload, passenger comfort, and fuel will determine that extent to which significant airframe modifications will be undertaken by the industry to reduce drag in the years ahead.

One additional fuel savings possibility not directly related to weight and drag resistance is the increase in production of pressurized turbocharged aircraft. These aircraft are capable of flying at high altitudes where increased speed results from lower air density, and pressurization adds to pilot and crew comfort. Fuel is saved because of increased airspeed and other factors, such as the ability to fly over bad weather instead of around it. The emergence of more single engine and light twin pressurized/turbocharged aircraft is expected over the next ten years.

3.2 Pilot Awareness and Education

Throughout this study, input from aircraft and engine manufacturers, owners and operators of large fleets of general aviation aircraft, certified flight instructors, and FAA personnel has led to the general consensus of opinion that pilot fuel management is the area of largest potential fuel savings in small aircraft. Most of the pilots in general aviation today were trained at a time when fuel was inexpensive and fuel management not very important for typical personal type flying. If pilots can be made aware of the savings possible when using proper fuel management procedures and be educated in properly utilizing the appropriate procedures for the aircraft they operate and the missions they fly, there exists the possibility of improving the nation's gasoline situation and reducing hourly operating costs for the pilot as well.

3.2.1 Assessment of Fuel Savings Potential

Normally aspirated aircraft piston engines at cruise power require leaning (decreasing) of the engine fuel/air ratio at altitude to maintain efficient engine operation because of the decreased density of the ambient air. However, basic air-cooled engine design considerations require rich mixtures and excess fuel at high power settings (above 75% of maximum power) to provide necessary engine cooling. Therefore, most small general aviation aircraft incorporate a manual mixture control which enables the pilot to adjust the fuel/air ratio entering the engine from the carburetor or fuel injection system as differing flight and power conditions require.

Correct mixture adjustment is important for both economy and engine life. At cruise power conditions, excessively rich mixtures result in loss of power and waste of fuel. Very lean mixtures cause a loss of power and under certain high power conditions, serious engine overheating. Since many aircraft do not have the adequate instrumentation needed to precisely set correct mixture, and many pilots are not cognizant of proper leaning techniques and are fearful of damaging engines by excessive leaning, it is suspected that overly rich mixtures are often used and fuel is wasted.

Industry representatives support this theory but no quantitative data could be found concerning the extent to which improper leaning is practiced. Since a comprehensive survey or interview program was beyond the scope of the study, engineering judgment, experience, and available engine performance data were used to develop the following estimate of potential fuel savings possible with proper pilot fuel management in the fleet of small single and twin engine piston aircraft.

In Table 3-4, representative aircraft were chosen for the four aircraft categories addressed in this study. Fuel consumption is listed for full rich operation, and for mixture leaned to peak exhaust gas temperature (EGT)* at 75% power and 4000 ft. altitude. The difference represents the quantity of fuel wasted if the engine is not leaned at cruise.

By multiplying the fuel saved for these representative aircraft by the estimated annual hours spent at cruise for each aircraft category, and a constant representing the estimated percentage of the fleet burning excess fuel by using overly rich mixtures at cruise power conditions, possible fuel savings attributable to proper leaning were derived. Estimates of the proportion of total flight hours spent at cruise and the extent of the application of proper leaning techniques (see Table 3-5) can be revised to increase the confidence in the estimate as more information becomes available.

The savings for proper leaning of 476,577 barrels indicated in Table 3-6 represents a yearly aviation gasoline savings for general aviation of about 4%.

Fuel savings can also be achieved by reduced cruise power (and air speed) in much the same way as lowering highway speed limits for automobiles increases mileage. The aircraft in this study are characteristically designed to cruise at 55% to 75% engine power. A 10% reduction in cruise power results in approximately an equal fuel savings, while the resulting increase in total trip time due to the lower air speed probably will be nearly unnoticed. Using the values from Chapter 2 (Table 2-3) for average hourly fuel consumption, and from this section (Table 3-5) for estimated hours spent in cruise, 10% reduced cruise power would save approximately 686,459 barrels or 6% of the total general aviation gasoline consumption if universally adopted by the general aviation small aircraft fleet. Thus the savings from proper leaning and reduced cruise power (both accomplished through improved pilot education) total 1.163 million barrels of gasoline.

One additional fuel savings technique involves trip planning for minimum fuel consumption. Winds aloft data can be used to plan cruise at altitudes where the wind direction and velocity may increase (or at

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* Maximum fuel economy occurs near peak EGT for an engine operating at or below normal cruise power. However, design considerations preclude some aircraft engines from operating at peak EGT for some higher cruise power settings, and therefore the average fuel savings indicated (18%) is not achievable in all aircraft.

TABLE 3-4 REPRESENTATIVE AIRCRAFT FUEL CONSUMPTION

Category	Aircraft	Fuel Consumption (Gal/Hr) Full Rich	Leaned	Difference	(%)
Single Engine 1-3 Seats	Cessna 152 110 HP	7.3	5.9	1.4	(19.2)
Single Engine 4+ Seats	Cessna Cardinal 180 HP	11.9	9.7	2.2	(18.5)
Twin Engine 1-6 Seats	Piper Aztec 2x250 HP	32.4	27.2	5.2	(16.1)
Twin Engine 7+ Seats	Britten-Norman Islander 2x300 HP	38.0	31.2	6.8	(17.9)
			Average Difference		(17.9%)

Cruise Conditions, 4000 ft altitude, 75% power

Source: AVCO Lycoming, Williamsport Division

TABLE 3-5 AIRCRAFT USAGE BY CATEGORY

Category	Total Hours Flown*	Hours Per Aircraft*	Hours at Cruise Power**	Leaning ** Constant***
Single Engine 1-3 Seats	8,972,836	156	80	.75
Single Engine 4+ Seats	15,943,601	173	115	.50
Twin Engine 1-6 Seats	3,630,265	241	160	.20
Twin Engine 7+ Seats	2,321,563	373	250	.10

* Source - Reference 1

** Source - Estimates, Arthur D. Little, Inc., Cambridge, Mass., under contract DOT-FA-79-WA1-041

*** This value represents the percentage of the possible savings actually available realizing that some operators do lean to some extent. It is assumed that pilots become more cognizant of proper leaning as the complexity of the aircraft they operate (and their skill requirements) increases.

TABLE 3-6 FUEL SAVINGS BY PROPER LEANING

Category	Active Fleet Size	X	Yearly Fuel Savings (Gal) Average Aircraft	=	Yearly Fuel Savings (Gal) Category
Single Engine 1-3 Seats	57,340		84		4,816,560
Single Engine 4+ Seats	91,960		127		11,632,940
Twin Engine 1-6 Seats	15,074		166		2,508,314
Twin Engine 7+ Seats	6,226		170		1,058,420

Total Estimated Fuel Savings = 20,016,234 Gallons

= 476,577 Barrels

least not decrease) ground speed. Direct routes can be chosen to minimize distance to the destination. Climbs and descents can be tailored to minimize fuel consumption. While the actual extent of fuel savings attributable to fuel efficient trip planning cannot be easily estimated because of the many variables involved, it is believed that significant conservation is possible with increased utilization of these techniques by a large segment of fleet..

The estimates derived in this section were based on 1977 usage data; however, assuming that aircraft fleet mix, aircraft/engine design, and proportion of hours flown at cruise remain approximately the same, these estimates of percent fuel savings attributable to proper leaning and reduced cruise speed are constant for future years. Therefore, a significant national aviation gasoline savings seems quite possible with the future implementation of improved fuel management techniques.

3.2.2 Awareness and Education Programs

Various programs have been suggested to increase pilot awareness of potential fuel savings and provide training for the implementation of fuel conservation techniques. An era of inexpensive fuel and misconceptions concerning proper engine operation have caused the average pilot today to be less than fuel conscious; but current fuel prices of well over one dollar a gallon are making fuel a significant portion of operating cost and spot shortages are beginning to raise attention. In today's environment, therefore, a conservation program may be well received. However, since safety and reliability will continue to be aviation's primary concerns, it is important that fuel saving techniques be taught in such a way that safety in general aviation is not derogated, and that increased conservation in no way degrades aircraft performance or reliability.

Various fuel conservation programs aimed at the pilots of small general aviation aircraft will be presented in the remainder of this chapter. It is not possible to identify the actual fuel savings potential of each program; however, as seen in the previous section, combined savings of approximately 10% of the fuel consumed yearly are possible with modified pilot techniques.

FAA Sponsored Programs

Proper fuel management and conservation techniques could be taught in conjunction with official FAA programs:

- --Testing: Pertinent questions could be included in the written examinations for pilot ratings such as Private or Commercial pilot, and Certified Flight Instructor. Working knowledge could further be assessed during respective flight tests by official FAA flight examiners.

--Biennial Flight Reviews: Pilots are currently required to undergo a competence review every two years by a certified flight instructor. Knowledge of fuel management could be a required area of testing and review.

--Seminars and Literature: The FAA currently is conducting an Accident Prevention Program through its General Aviation District Offices (GADO) nationwide to promote general aviation safety. This is a growing program that has received industry support and has been well received by pilots. Since proper fuel management is closely linked to aviation safety, the program could be used to reach pilots with fuel saving information and techniques through meetings, seminars, clinics and literature. A new drive to encourage private pilot refresher training began July 15, 1979, as part of the Accident Prevention Program. Three hours of flight training and attendance at a safety clinic is needed to complete this voluntary course; which could be an ideal vehicle for a review of basic leaning and approved fuel conservation methods.

--Regulations: Various changes in Federal Aviation Regulations could result in national fuel savings, for example: a reduction in required flight hours to receive and retain ratings, and allowance of more use of flight simulators. However, in this area, fuel savings must be seriously weighed against possible losses in pilot proficiency due to the reduction in actual hours flown.

Industry Programs

General aviation aircraft and engine manufacturers, and fixed base operators (flight schools, flying clubs) could promote fuel conservation through various means.

--Pilot's Operating Handbook: The Pilot's Operating Handbook (POH) is furnished with every aircraft by the airframe manufacturer and contains the information necessary for safe operation of the aircraft. However, the data contained concerning proper leaning, engine operation, and fuel management is, in many cases, disjointed, unclear, and incomplete. Information from the engine manufacturer is sometimes contradicted by the POH. A clearly written, comprehensive supplement concerning proper fuel management could be included either as part of the POH or, if found to unacceptably expand an already lengthy handbook, as a supplementary document. It is believed that pilots would use a clear, helpful, well-written manual to maximize fuel economy and reduce operating costs.

--Flight Schools and Flying Clubs: Rising fuel costs are beginning to be felt by fixed base operators. One specific flight school/flying club reported fuel costs as 19% of rental revenues and 40% of variable operating costs in 1978. Therefore, there is an incentive to teach fuel management to students and rental pilots. The average instructor has contact with a minimum of 10 students a year, and so the opportunity exists on a national level for reaching a large number of active pilots through flight schools. Unfortunately, there are indications that flight instructors themselves are not particularly cognizant of proper fuel management methods. Therefore, an educational program for instructors may also need to be incorporated by fixed base operators or the FAA. One possible avenue is the FAA flight instructor revalidation clinics. Another possibility is the recording by flight school operators of the fuel usage of individual instructors during dual (instructional) flights. Instructors using more fuel than average could be briefed on the potential for fuel savings, and incentives could be offered by the flight school operators for conservation and reduction of operating costs.

One further fuel saving possibility related to fixed base operation is the rental basis of aircraft. Most aircraft are rented on a "wet" basis, i.e., fuel is included in the rental rate. There is, therefore, no incentive for saving fuel. When renting an aircraft "dry" the pilot pays for the fuel he uses and may therefore be more apt to conserve fuel to reduce his costs. However, there are definite problems with "dry" rental. Fueling aircraft after every flight, recording fuel used, and computing fuel cost represents an increased cost to the fixed base operator and increases the complexity of the rental operation. Safety aspects must also be seriously considered when evaluating "dry" rental since pilots would possibly be tempted to "stretch" fuel and range with potentially disastrous results.

3.3 Air Traffic Control Action

In this section possible fuel savings for single and twin engine piston general aviation aircraft by modifications to the Nation's Air Traffic Control (ATC) system are discussed. It should be noted that much emphasis is currently being given to fuel savings through changes in ATC procedures, but these programs are utilized to a greater extent by the large, turbine powered aircraft than by the single and twin engine general aviation aircraft discussed in this study. The larger turbine powered aircraft, composed primarily of the airline fleet, travel over fixed routes, have sophisticated instrumentation for navigation, and cruise, climb and descend more precisely, and are continuously under the direction of ATC. These aircraft are flown by professional crews backed by strong training and support functions. Because of the magnitude of the fuel consumed per hour by these aircraft, and the large number of hours flown, there is very strong incentive for the operators to request and support the initiation of more efficient ATC procedures. In the forefront are those ATC procedures which can prevent fuel-wasting airborne holds through the use of techniques such as flow control, gate

holding, the use of optimum holding and priority landing procedures when holding in a stack, reduced final approach spacing, profile descent procedures, and optimum climb profiles.

However, most of these procedures are not utilized to a large extent by the single and twin engine piston aircraft addressed in this study. In the first place, ATC delays are generally experienced only by those aircraft being operated under Instrument Flight Rates (IFR). Pilots flying under Visual Flight Rates (VFR) are responsible for navigation and routing themselves and are usually not in contact with ATC en route. Only about 30% of the total general aviation activity at towered airports is IFR; therefore, a large majority of operations do not encounter delays due to Air Traffic Control. Second, differences in engine operation and aircraft design make procedures developed for turbine aircraft not necessarily optimal for the slower, lower altitude, piston aircraft.

Certain ATC programs could conceivably be expanded to include smaller general aviation aircraft, although the impact on overall general aviation fuel consumption is expected to be quite small:

--Flow Control

In this procedure, aircraft are held at the gate (or tie-down area), or slowed down enroute, when landing delays occur at the destination airport. This procedure is more fuel efficient than holding over the destination, since engine start-up and departure can be delayed, or a more economical cruise can be set up when informed en route of a landing delay.

--Revised SID's and STAR's

A Standard Instrument Departure (SID) refers to an ATC coded departure routing which is established at certain airports to simplify departure clearance procedures. A Standard Terminal Arrival Route (STAR) is an ATC coded arrival route, analogous to a SID. The SID and STAR procedures were originally designed with emphasis on expediting the movement of traffic in high traffic areas as opposed to the consideration of fuel conservation. SID's and STAR's are also designed for all segments of aviation.

Because of the performance characteristics and maneuverability of small general aviation aircraft, special SID's and STAR's could possibly be developed for them separately and could be primarily aimed at reducing fuel consumption during departures and approaches.

--Separate General Aviation Runways

Fuel savings can be realized if separate runways are allocated to general aviation aircraft. This system permits more expeditious processing of heavy turbine aircraft as well as general aviation by precluding delays and airborne speed reductions to permit proper separation of aircraft.

--Area Navigation Routes

The current air route structure has significant fuel related disadvantages. While navigational aid stations are located to provide nearly straight line flight between major cities, a certain amount of non-direct routing is encountered, and some fuel could be saved by means of a navigation system offering direct point-to-point flight. This is especially true of general aviation where travel is often to out-of-the-way locations.

Area navigation (RNAV) equipment implements direct routing from the origin to the destination by using data from standard VOR navigation stations and an on-board computer to establish imaginary radio beacons to which the airplane is flown, thus allowing straight-line flight between points. Although only a small number of general aviation aircraft have RNAV today, advances in electronics should make this equipment affordable to these pilots in the not too distant future. ATC procedures will need to be modified to accept RNAV flight plans that do not use the standard airways.

CHAPTER 4

4. FEASIBILITY OF ENERGY SAVINGS OPTIONS, RECOMMENDATIONS

The feasibility of the potential fuel saving options introduced in Chapter 3, i.e., cost, reliability, pilot acceptance, and regulatory restrictions, is discussed in this chapter. Recommendations for actions required to implement these fuel savings options are included as a step toward a national fuel conservation program for small general aviation aircraft.

4.1 Hardware

4.1.1 Engine and Fuel Control

In Chapter 3, engine related hardware improvements were analyzed for potential energy savings. A conclusion reached from this analysis is that the current aircraft air-cooled, spark ignited piston engine is already an efficient powerplant when compared to available alternatives. Moderate gains in fuel economy (5-10%) are likely to be achieved in the near future with conventional hardware without substantial development programs or product redesign. However, substantial gains (greater than 10-20%) would probably require costly new development programs for both engines and airframes. It is questionable whether the potential cost impact to the aircraft industry of instituting a radical engine change would be justified by the fuel savings* although aviation gasoline availability and the desire for alternate fuel capability may change this conclusion somewhat in the years ahead. It is therefore recommended that a comprehensive cost/benefit analysis be conducted to assess the advisability of industry and government agencies, such as NASA, committing the necessary resources to developing, certifying, and integrating the following engine related, fuel saving designs into small general aviation aircraft:

1) Reduced speed, increased torque (manifold pressure) operation of conventional design turbocharged engine with new low speed propeller.

2) Lean combustion engine with variable ignition timing and advanced fuel injection system.

3) Aircraft diesel engine.

4) Electronic automatic mixture control.

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* It should be noted that the yearly production rate of small general aviation aircraft is rather low (16,500 aircraft shipped in 1977) and that the average service life of an aircraft is quite long (over 50 percent of the aircraft in service in 1977 were produced prior to 1960). Since major engine hardware improvements would be incorporated into new aircraft only, the per engine savings estimated in Chapter 3 would therefore apply to a fairly small percentage of the fleet for quite some time.

4.1.2 Airframe Modifications

Design modifications aimed at reduced aircraft weight and drag were identified in Chapter 3 as fuel saving hardware improvements. Since aircraft weight reduction leads to decreased lift and drag, wing area, engine power/size, and fuel capacity, the potential payoff is large and it is therefore recommended that composite material development for small general aviation aircraft be given high priority. Efforts aimed at aerodynamic cleanup and draft reduction should also be continued and a review of the latest advances in aerodynamics undertaken to assure that state-of-the-art techniques are currently being utilized in small aircraft design and that maximum feasible drag reduction is attained in new aircraft.

These programs for drag and weight reduction will be more costly than the industry can probably support. It is suggested that this research and development can be partially integrated into related programs, such as larger aircraft development, and possibly be sponsored and coordinated by a technically-oriented government agency such as NASA.

4.2 Pilot Programs

FAA personnel, manufacturers, flight school owners, flight instructors, and general aviation pilots were contacted to discuss the feasibility of the pilot awareness and education programs presented in Chapter 3. Results of these discussions have been combined with information gathered throughout the program to generate the following comments and recommendations concerning specific programs.

FAA Sponsored Programs

Biennial Flight Reviews and Flight Instructor Clinics

The content of the pilot's biennial flight review (BFR) is currently the responsibility of the individual flight instructor conducting the review. At this time the FAA does not intend to specify any mandatory topics for the BFR and therefore it does not seem feasible to propose a required review of fuel management as part of the BFR. However, if flight instructors are made aware of the fuel and cost savings possible by adopting proper fuel saving techniques, it is reasonable to expect that this material will be included in biennial flight reviews.

Under the auspices of the FAA, various clinics are conducted for the recertification of flight instructors. The FAA sends operations bulletins to these clinics whenever important items need to be brought to the attention of flight instructors. Preparation and distribution of an operational bulletin concerning fuel conservation techniques will be considered using this forum. As mentioned previously, the average flight instructor has contact with at least 10 students and pilots each year and therefore there is potential for reaching a significant percentage of the flying population through flight instructors.

Seminars and Literature

The FAA Accident Prevention Program (APP) already conducts seminars and distributes literature describing proper engine leaning techniques. Indications are that the APP will enjoy increasing success in reaching growing numbers of pilots in the future. Additional efforts will be considered for

preparing a comprehensive program on energy conservation in small general aviation aircraft for presentation as part of the APP. Industry cooperation should be solicited to assist in the preparation of a high quality program.

Testing

The content of the written examinations for airmen licenses and ratings are periodically examined and modified by the FAA. Energy conservation and fuel management should be given increased emphasis in future written examinations. The FAA will consider amending FAR Part 61 to require a demonstration of proper leaning and fuel efficient trip planning as part of the Private and Commercial pilot flight tests.

Regulations

Regulations concerning minimum flight hours required for ratings and the allowable use of simulators in lieu of actual flight time are currently being reviewed by the FAA. National fuel savings related to reduced flight hours and increased simulator time should be considered for inclusion in the analysis of the cost/benefit of changing current requirements.

Industry Sponsored Programs

Pilot's Operating Handbook

It is suggested that the airframe manufacturers (with assistance from the engine manufacturers) devote substantial effort to clarifying leaning techniques and proper engine operation in the Pilot's Operating Handbook (POH). A clearly written, comprehensive section discussing all aspects of proper fuel management (Cruise Control)* should also be included in new handbooks and be made available for older aircraft as well.

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* Mooney Aircraft Corporation has included a section in their 1979 Pilot's Operating Handbooks devoted to efficient operation of their aircraft entitled "Cruise Control." Included are "Nautical Miles Per Gallon Charts" which allow the pilot to choose (with winds aloft and ATC information) the most efficient trip profile (altitude, speed) to meet the pilot's needs. It is suggested that this material serve as a general guide for the development of new material for the Pilot's Operating Handbook.

It is believed that modifications to the POH are important both to increase pilot awareness of potential fuel savings and to dispel misconceptions concerning engine operation. Supplements to Pilot's Operating Handbooks should alleviate the pilot's doubts as to whether the general published data (engine manufacturers' bulletins, APP literature, ect.) actually can be safely applied to the pilot's aircraft, and will indicate official manufacturer approval of the techniques described.

Flight Schools

It is recommended that the owners and operators of flying schools and clubs stress fuel conservation with their instructional staff and customers. Monitoring of each instructor's fuel usage may be used to identify those that need additional training in fuel conservation. The increased emphasis on fuel conservation at the flight school operator level should filter down to the instructors and finally to the students and rental pilots. Because of the safety and logistics problems discussed in Chapter 3, it is not recommended to change aircraft from a "wet" to "dry" rental basis.

Costs

It is difficult to attempt to compute costs for these educational type programs. It is anticipated however that none of the recommendations made in this section (with the possible exception of the preparation of supplements to existing Pilot's Operating Handbooks) will be at all costly or require new personnel to implement. In light of the real possibility of conserving a significant percent of the estimated maximum possible savings of nearly 50 million gallons of aviation gasoline per year derived in Section 3.2, it is suggested that implementation of the recommended programs be given serious consideration.

4.3 Air Traffic Control Actions

In Chapter 3, the following ATC related procedures were identified as being possibly applicable to small general aviation fuel conservation programs:

Flow Control
Revised SID's and STAR's
Separate General Aviation Runways
Area Navigation Routes

It was beyond the scope of this preliminary study to attempt to estimate the actual fuel savings associated with these programs, because of time constraints and the many variables involved. However, because of the relatively few instrument operations flown by this segment of general aviation and the tendency for pilots to stay out of the busiest airports, it is believed that modified ATC procedures have the least potential for fleet fuel conservation of the three areas investigated. Therefore, while a feasibility study may be warranted, it is doubtful that significant fuel savings are possible as a result of ATC actions.

REFERENCES

1. Federal Aviation Administration, 1977 General Aviation Activity and Avionics Survey, U.S. Department of Transportation, Report No. FAA-MS-79-5, Washington, D.C., April 1979.

2. Federal Aviation Administration, FAA Aviation Forecasts Fiscal Years 1979-1990, U.S. Department of Transportation, Washington, D.C., 1978.

3. Energy Information Administration, Energy Data Reports, U.S. Department of Energy, Report DOE/EIA-0108/77, Washington, D.C., 1978.

4. Arthur D. Little, Inc., A Study of Technological Improvements in Automobile Fuel Consumption, Volume II: Comprehensive Discussion, Report No. DOT-TSC-OST-74-40. II, December, 1974.

5. Rezy, Bernard J.; Stuckas, Kenneth J.; Tucker, J. Ronald; Meyers, Jay E.; Concepts for Reducing Exhaust Emissions and Fuel Consumption of the Aircraft Piston Engine, Teledyne Continental Motors, SAE Paper 790605, 1979.

6. Mooney Aircraft Corporation, M20K 1979 Pilot's Operating Handbook, Kerrville, Texas, 1978.

7. Willis, Edward A., General Aviation Internal Combustion Engine Research Programs at NASA-Lewis Research Center, NASA TM 78891, 1978.

1. CONTROL NUMBER	DEPARTMENT OF TRANSPORTATION—FEDERAL AVIATION ADMINISTRATION **GENERAL AVIATION ACTIVITY and AVIONICS SURVEY** **(As of December 31, 1977)**	*Form Approved* OMB No. 04—R0185

This report is authorized by Section 311 of the Federal Aviation Act of 1958, as amended. While you are not required to respond, your cooperation is needed to make the results of this survey comprehensive, accurate and timely. Information collected in this survey will be used for statistical purposes only and not to disclose individual aircraft activity.

2 ☐ "X" here if you operate your aircraft principally as an air carrier (under FAR 121 or 127). If so, DO NOT complete remainder of form. However, please return to address shown below ▼

3. AIRCRAFT CHARACTERISTICS

N—

INSTRUCTIONS: Please answer questions for the aircraft identified at right.
Mail the completed questionnaire in the enclosed postage paid envelope to

Federal Aviation Administration
P.O. Box 26045
Oklahoma City, Oklahoma 73126

4. What were the total lifetime airframe hours as of December 31, 1977? .... HOURS ☐

5. Was aircraft flown in Calendar Year 1977?
1 ☐ **Yes** 2 ☐ **No (Skip to question 9)**

6. HOURS FLOWN DURING CALENDAR YEAR 1977

a. If you did not own aircraft for entire year, "X" box and include previous owner's hours in your estimates. → "X" ☐

		HOURS
EXECUTIVE—Corporate flying with professional crew	b.	
BUSINESS—All non-executive flying for business reasons	c.	
PERSONAL—Individual flying for personal reasons	d.	
AERIAL APPLICATION—Agriculture, health, forestry	e.	
INSTRUCTIONAL—Flying with or under supervision of a flight instructor	f.	
AIR TAXI—All Part 135 passenger, cargo, and mail operations, including charter	g.	
INDUSTRIAL/SPECIAL—Patrol, survey, photo, hoist, etc.—Other than Part 135	h.	
AIRCRAFT RENTAL BUSINESS—Commercial flying club, leased and rental aircraft activity	i.	
OTHER—R&D, government, air show, sales, parachuting, etc.	j.	

7. Was this aircraft flown on an Instrument Flight Plan in 1977? 1 ☐ **No** 2 ☐ **Yes → Hours flown** → ☐

8. Estimate of this aircraft's average rate of fuel consumption (gal./hr.) during 1977 .... GAL./HR ☐

9. State (Abbreviation) in which aircraft was based as of December 31, 1977 .... STATE ☐

10. Was this aircraft on long-term lease during 1977? *(Principal use for three months or more by operator other than owner.)*
1 ☐ **Yes** 2 ☐ **No**

Continue with Question 11.

11. AVIONICS EQUIPMENT CAPABILITY ("X" ALL boxes that reflect this aircraft's current capability.)

VHF COMMUNICATIONS EQUIPMENT		"X"
VHF Communications System:		
360 Channels or less	a.	☐
720 Channels or more	b.	☐
More than one comm. system	c.	☐
No VHF Communications Equipment	d.	☐
TRANSPONDER EQUIPMENT		
4096 Code	e.	☐
Altitude Encoding Equipment	f.	☐
No Transponder Equipment	g.	☐
NAVIGATION EQUIPMENT		
VOR Receiver:		
100 Channels	h.	☐
200 Channels	i.	☐
More than one VOR Receiver	j.	☐
Automatic Direction Finder (ADF)	k.	☐
Distance Measuring Equipment (DME)	l.	☐
Area Navigation Equipment (RNAV)	m.	☐
Long Range Nav. (Doppler, INS, Other)	n.	☐
Automatic Pilot	o.	☐
Radar Altimeter	p.	☐
Weather Radar	q.	☐
No Navigation Equipment	r.	☐
ILS RECEIVING EQUIPMENT		
Localizer	s.	☐
Marker Beacon	t.	☐
Glide Slope	u.	☐
Microwave Landing System	v.	☐
No ILS Receiving Equipment	w.	☐

THANK YOU FOR YOUR COOPERATION

FAA Form 1800—54 (9-77)

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